

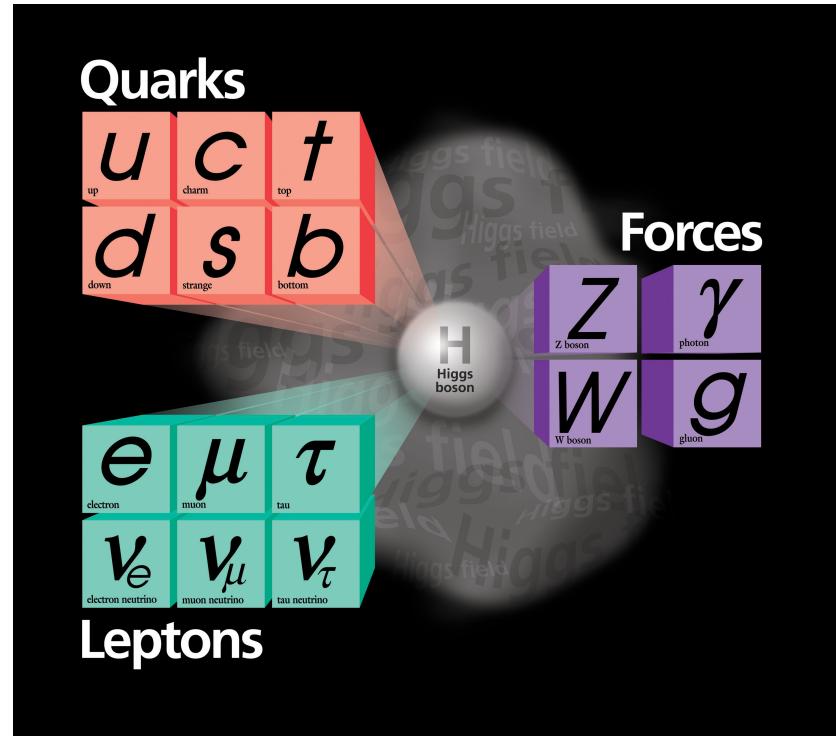


# Status of the NOvA Near Detector Prototype

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For the NOvA Collaboration

# Neutrinos and new Physics

- Neutrinos are light, neutral fundamental particles.
- They interact very rarely through the Weak Force even though neutrinos are extremely abundant:
  - trillions of neutrinos pass through you every second!
- The Standard Model of Particle Physics treats neutrinos as massless particles.
- Experimental observations made by the SuperK and SNO experiments verified neutrinos oscillate into different flavors, indicating that they have mass.



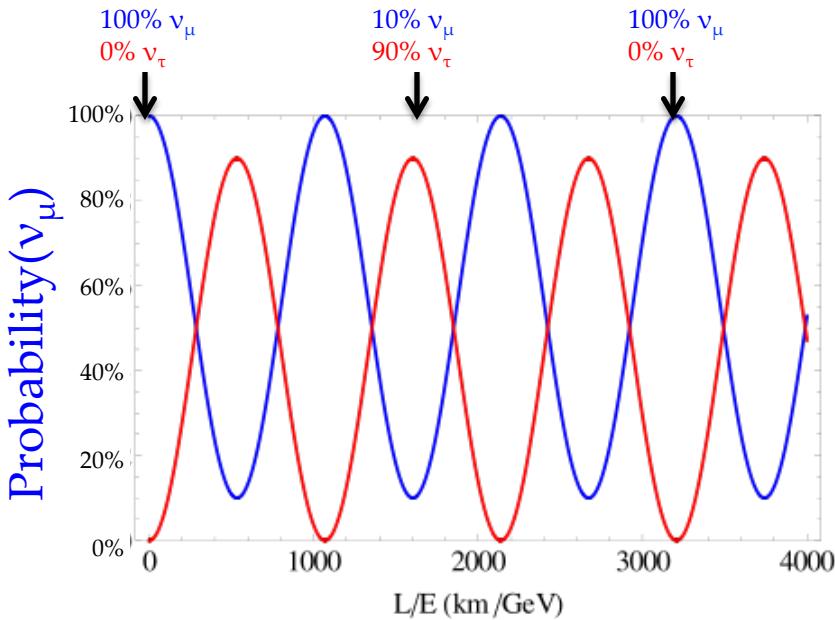
**Neutrino masses are physics beyond our best model of the Universe**

# Neutrino Oscillations

- Neutrinos have mass and thus they oscillate.
- There is a non-zero probability of detecting a different neutrino flavor than that produced at the source.
- In the case of a two neutrino world, we can write the probability:

$$\begin{pmatrix} \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \nu_2 \\ \nu_3 \end{pmatrix}$$

$$P(\nu_\mu \rightarrow \nu_\tau) = \sin^2(2\theta) \sin^2\left(\frac{1.27\Delta m_{32}^2 L}{E_\nu}\right)$$

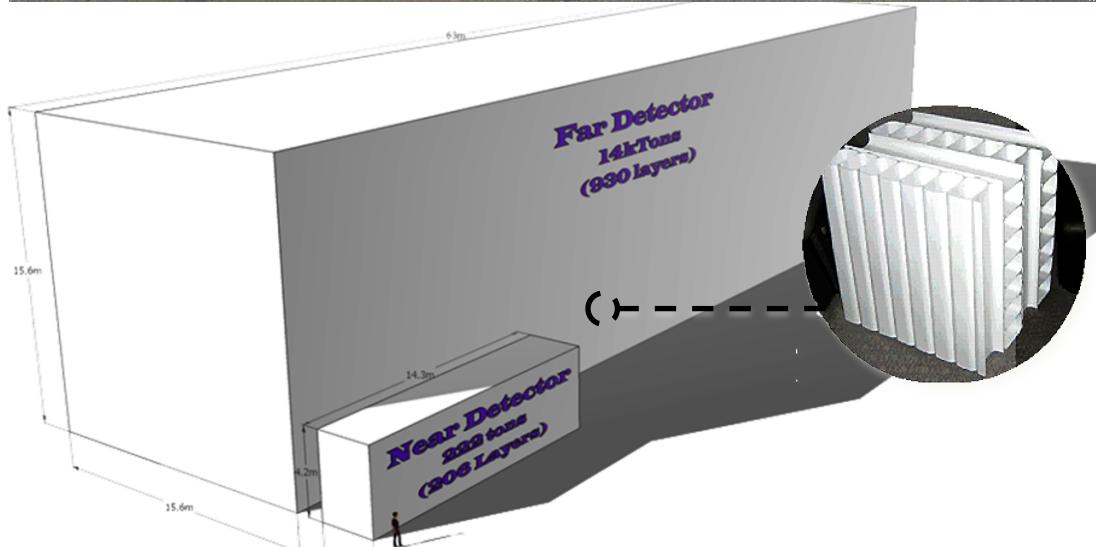
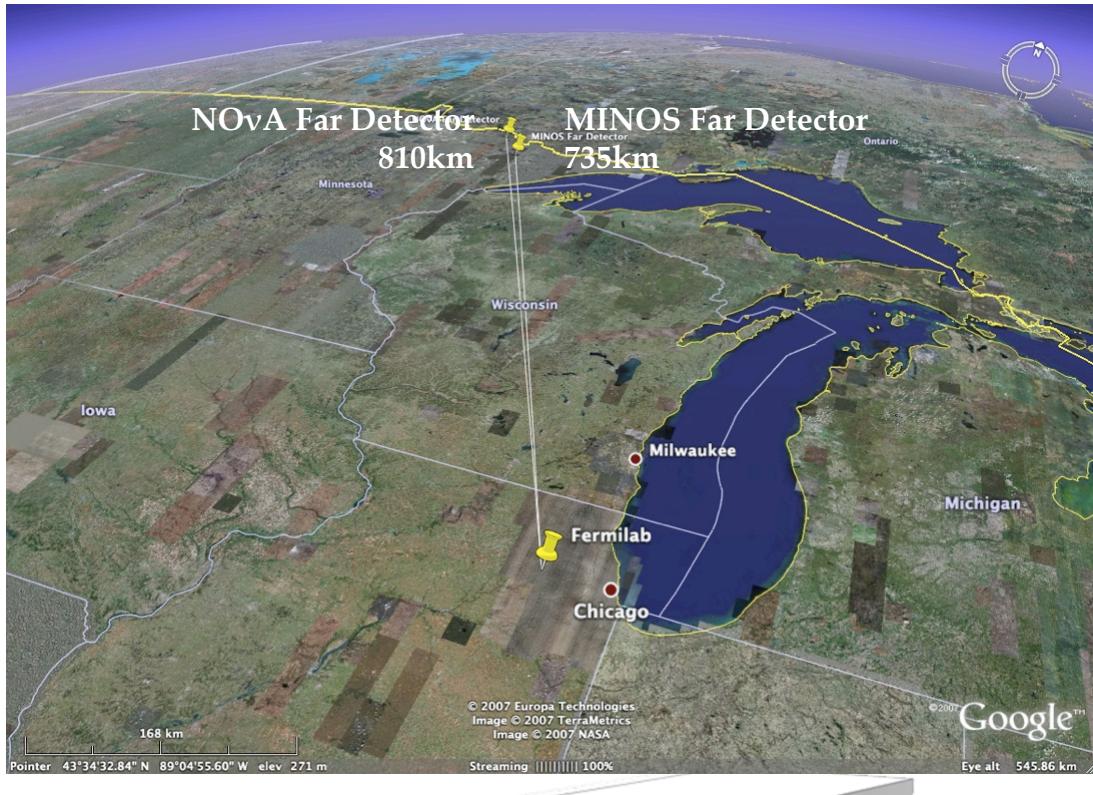


- But, we know there are three neutrinos.
- In light of the recent experimental results from the Daya Bay experiment, the NOvA experiment is in an exciting position to make further insights into other important neutrinos properties.

# NOvA

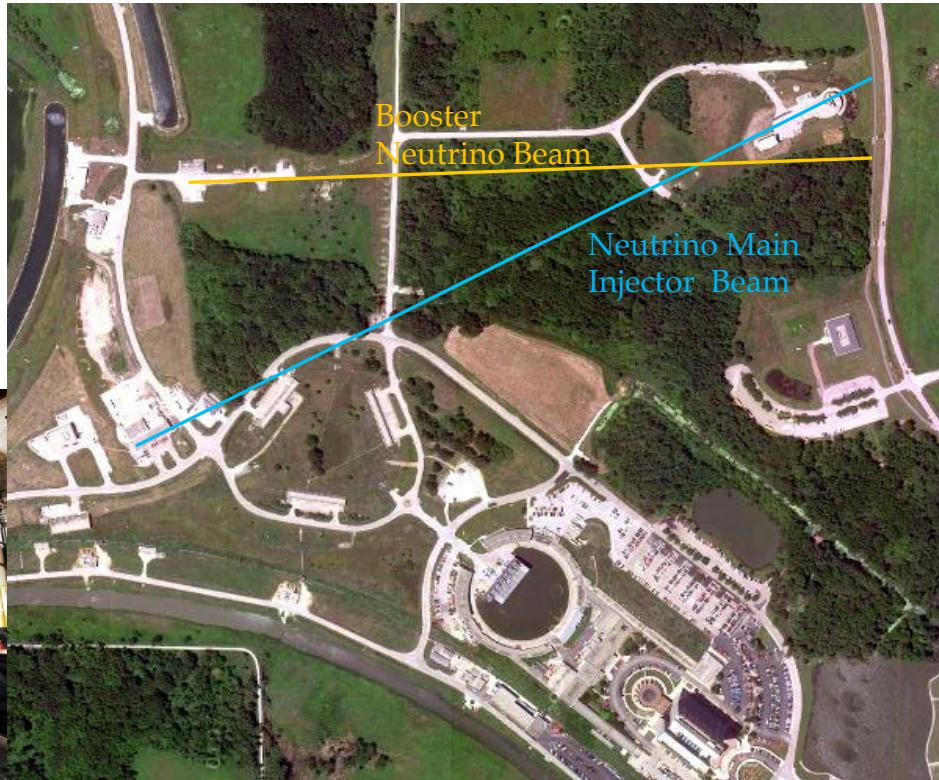
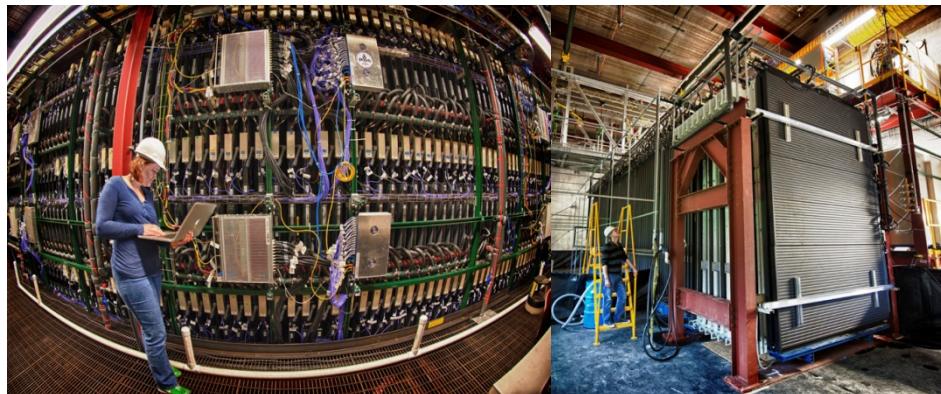
## NuMI Off-axis $\nu_e$ Appearance

- NOvA is a long-baseline experiment designed to observe electron neutrino appearance in a muon neutrino beam.
- NOvA will measure important neutrino properties such as:  $\theta_{13}$ ,  $\delta_{CP}$  and the mass hierarchy.
- NOvA's Near and Far detectors are 14 mrad off-axis of the World's most intense muon neutrino beam (NuMI).
- Totally active detector made of PVC and filled with liquid scintillator.
- Light is collected by wavelength shifting fibers in 360000 cells (far) and 16000 cells (Near).



# NOvA Near Detector Prototype

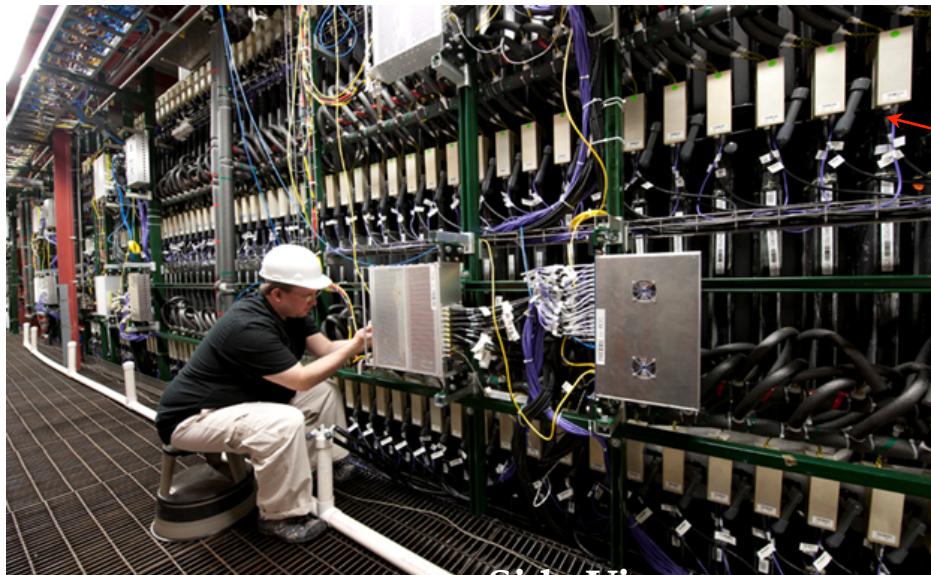
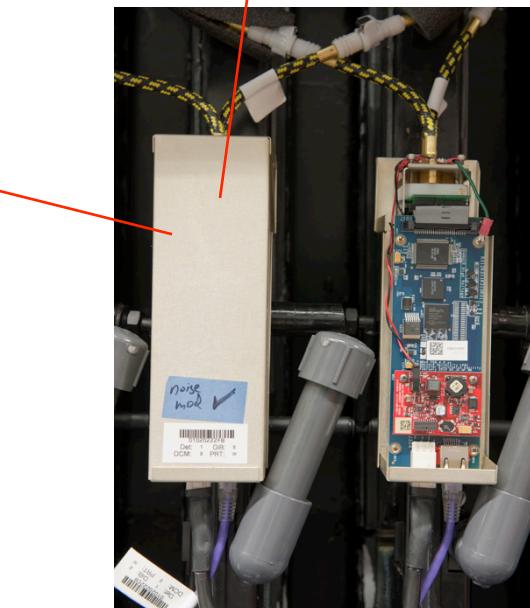
- The NOvA Prototype detector (NDOS) located on the surface at Fermilab.
- Uses the same materials and technologies as the Near and Far detectors.
- The NDOS is  $\sim 6.1^\circ$  off the NuMI beam axis and on the Booster beam axis.



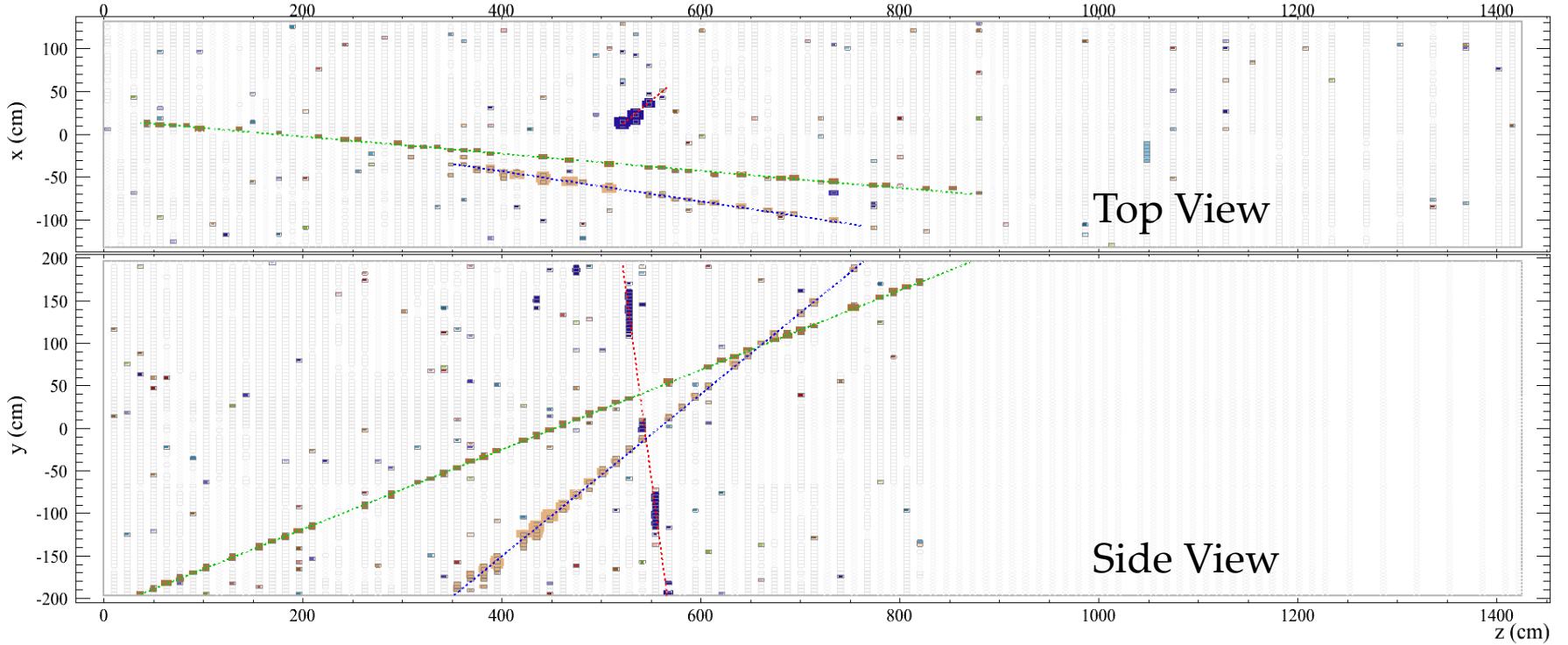
- Goals:
  - Testing assembly techniques for the Near and Far Detectors.
  - Installing, operating, testing the NOvA electronics and DAQ.
  - Developing reconstruction and calibration methods, and physics analyses.

# Assembly and Operations

- Used prototype detector to test assembly techniques and detector parts:
  - Redesigned module manifolds and changed module pressure testing procedure to avoid potential cracks.
- Gained experience in qualifying and filling scintillating oil.
- Tested avalanche photodiodes (APDs) in realistic operating conditions:
  - Developed surface coating for bare APDs to protect the silicon surface from potential contact with contaminants.
  - Added an active air drying system to keep out condensation due to cooling.

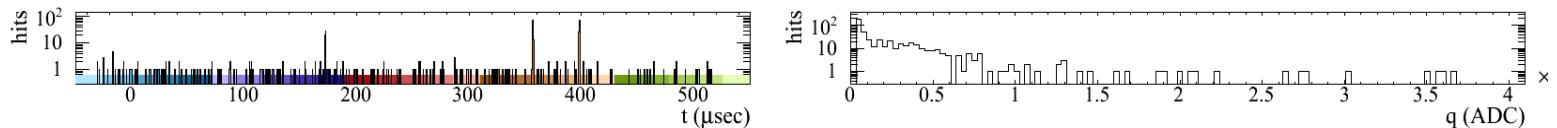


# Cosmic Ray Muon Data



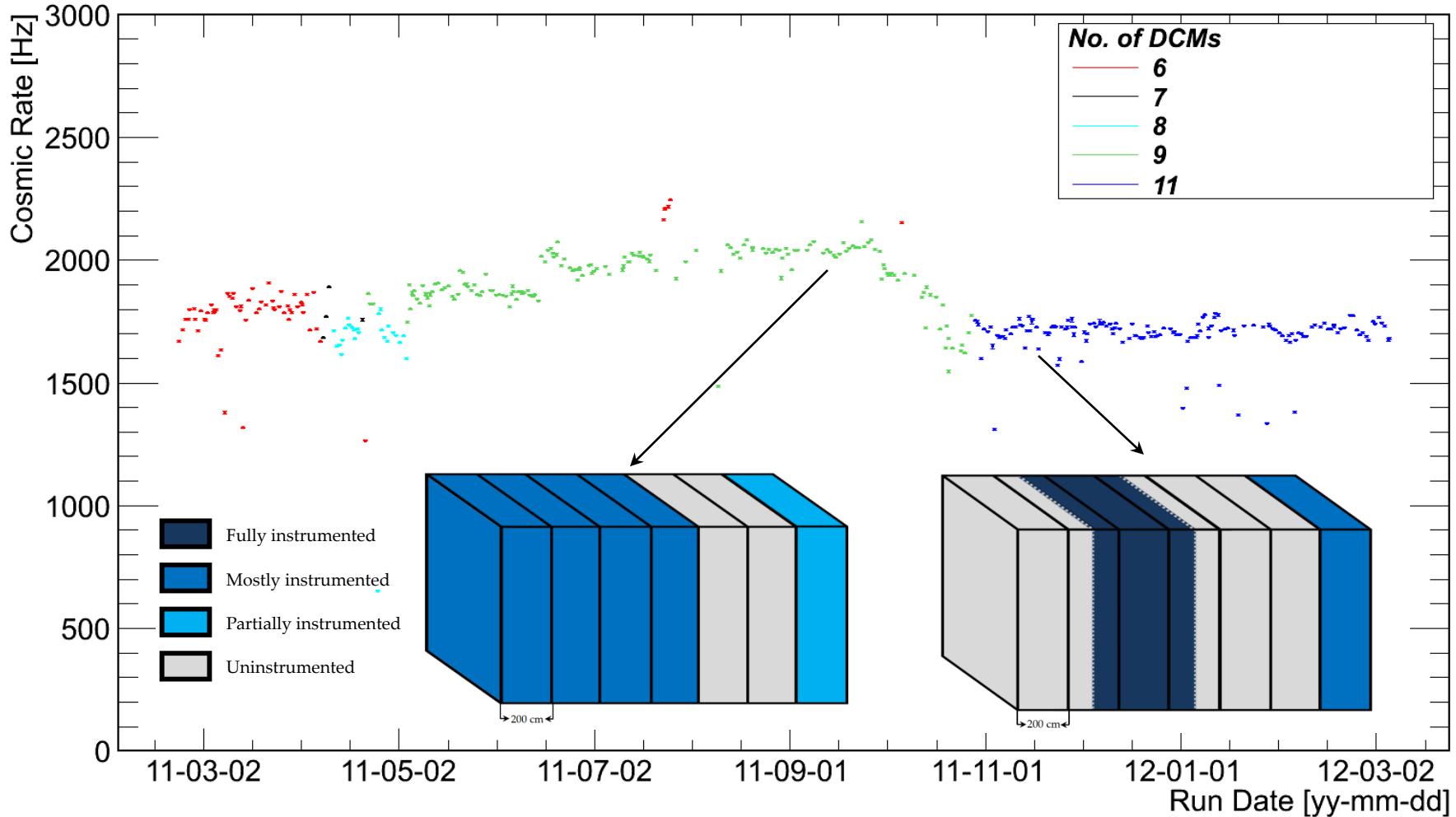
NOvA - FNAL E929

Run: 11994 / 1  
Event: 47084 / CAL  
UTC Fri Apr 15, 2011  
20:14:20.368928992



- Reconstructed cosmic ray muons are used for calibration and commissioning.
- Efficiency of the cosmic track reconstruction: >98%.

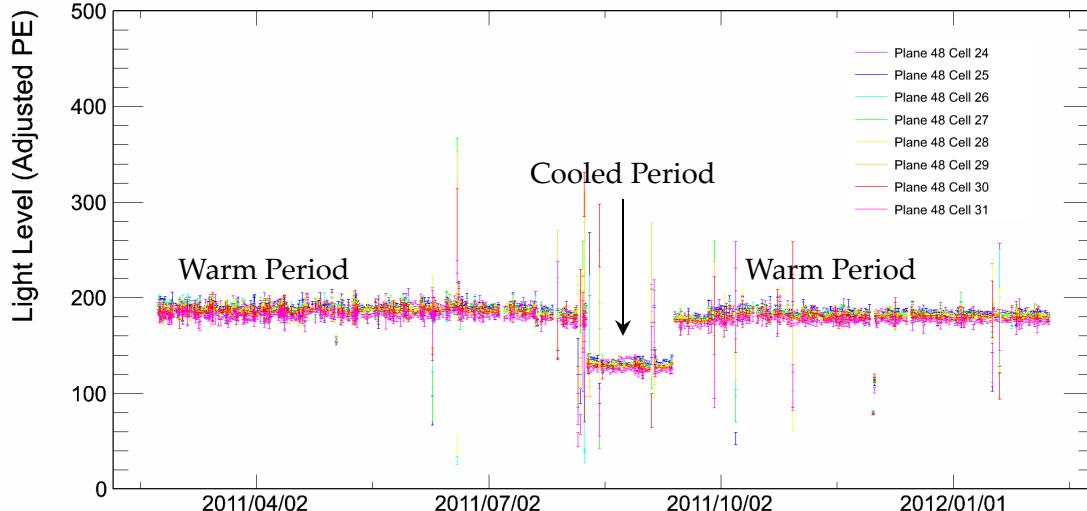
# Cosmic Ray Muon Rate



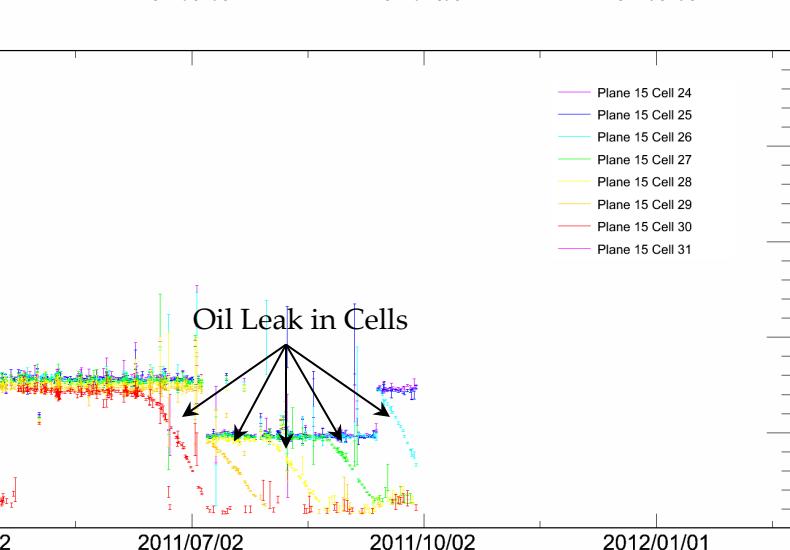
- Raw Expected Rate:  $1.95 \text{ kHz} = 1 \text{ min}^{-1}\text{cm}^{-2}$  (PDG – expected rate at surface of Earth)  $\times 1.17 \times 10^5 \text{ cm}^2$ .
- Variation in early data reflects changes in the configuration of the detector. Completed configuration results in stable rate.

# Light Level Stability

Mean Energy Deposition of Cosmic Ray Muons

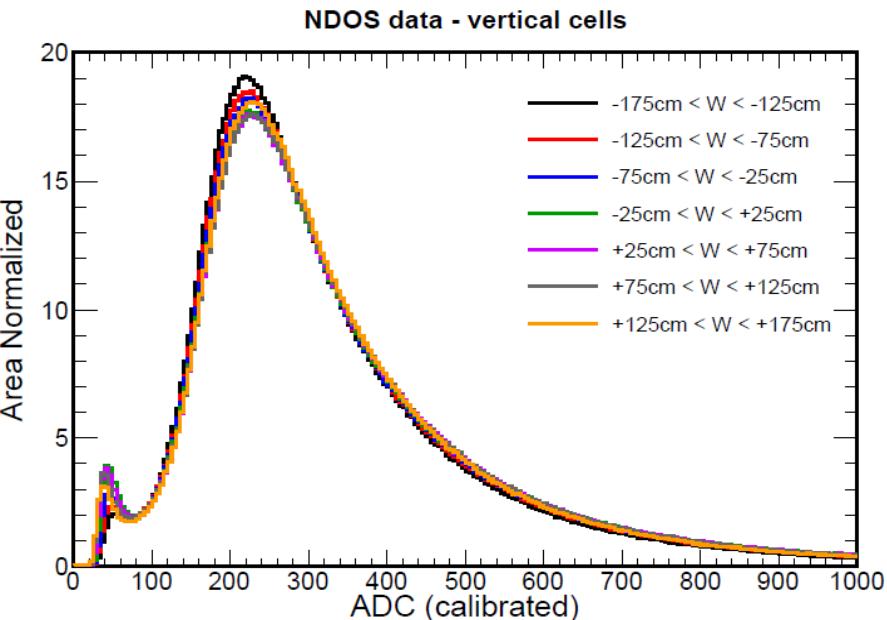
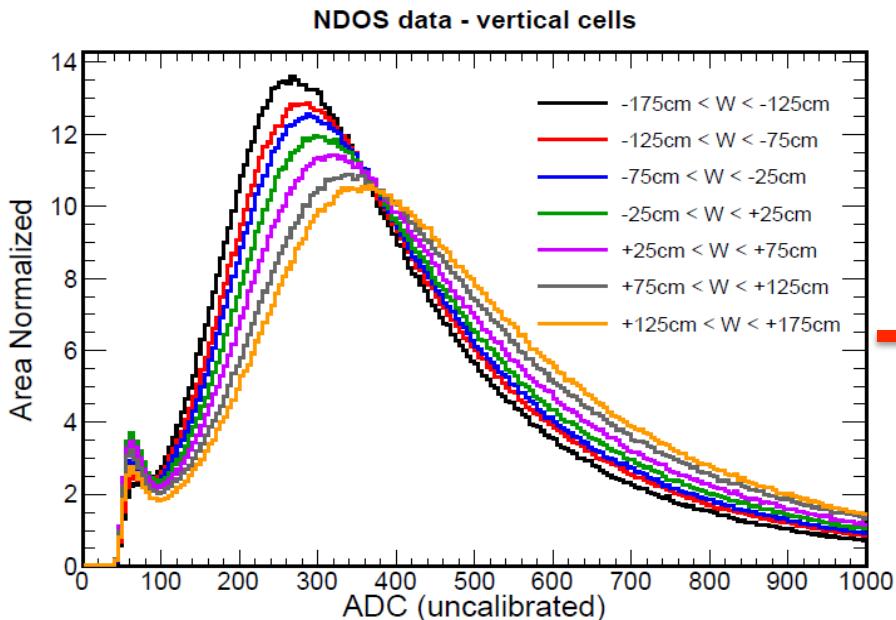
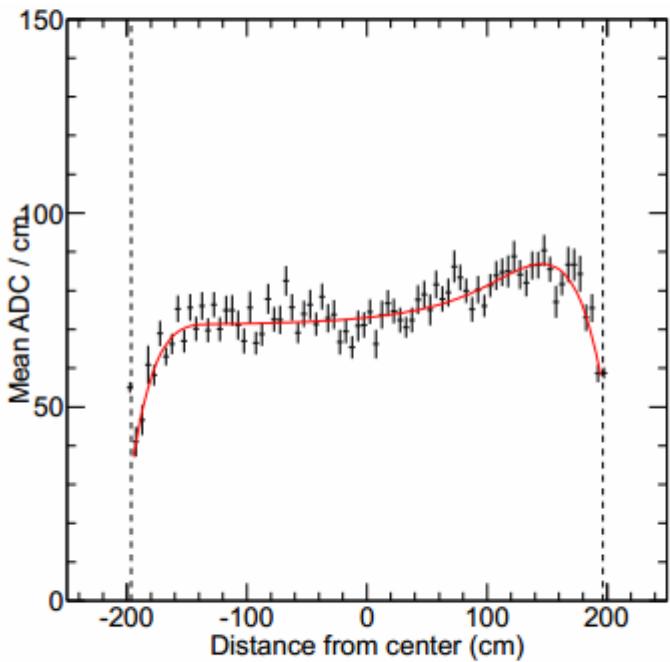


- Mean energy deposition of cosmic ray muons allow us to study the light level stability per cell.
- Light levels are uniform over time.
  - Changes on groups of cells are due to special running conditions with cooled APDs.
  - Cell by cell change shows an oil leak in a plane.
- These studies will be used in commissioning and calibration of the Near and Far Detectors.



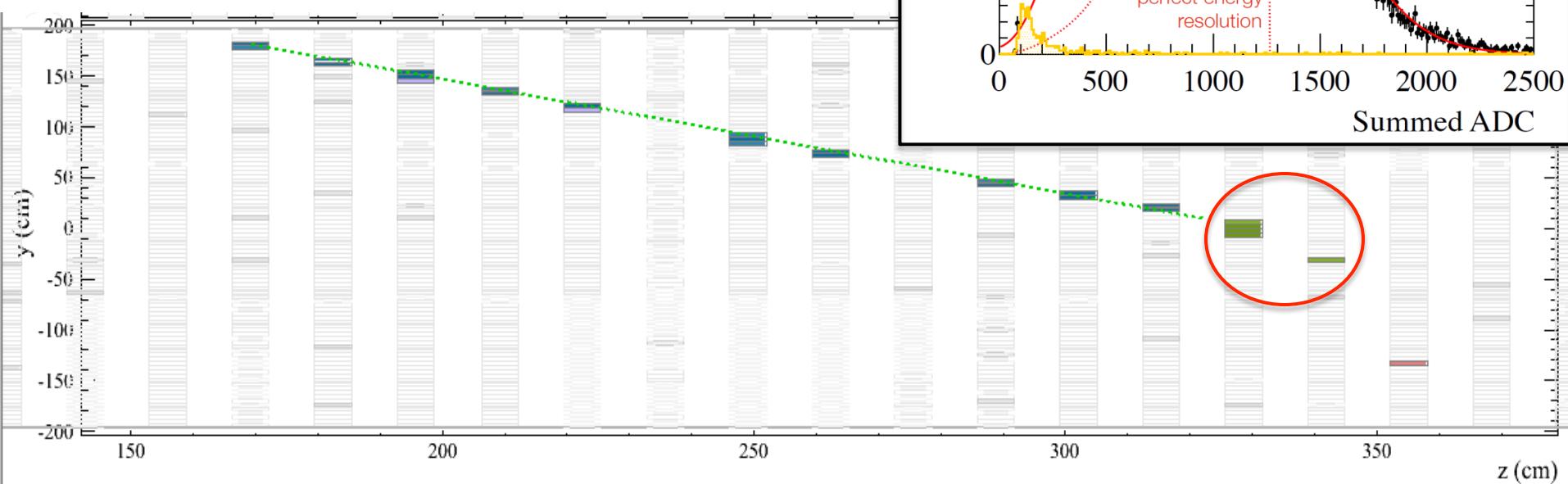
# Attenuation Calibration

- Use cosmic ray muons to study light attenuation response as a function of position.
- $W$  is the position along the cell length.

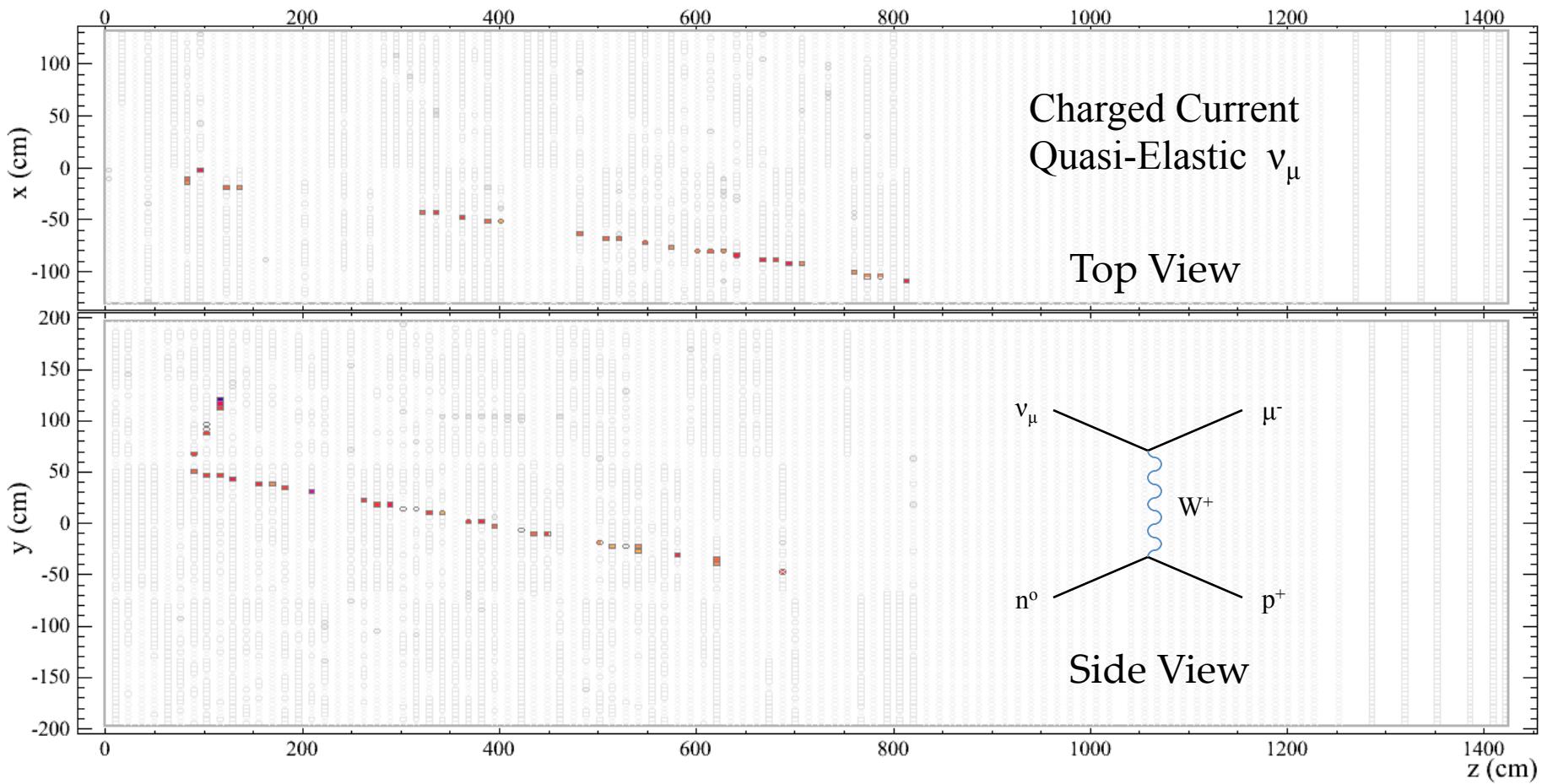


# Michel Electrons

- Found at the ends of contained muon tracks.
- Used as a part of the energy calibration of the detector.
- Typically has about 4 hits in the interaction.



# Neutrino Candidate – Data

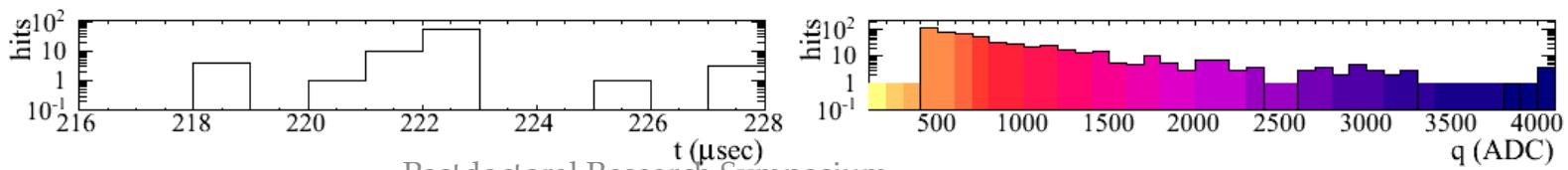


**NOvA - FNAL E929**

Run: 10893/8

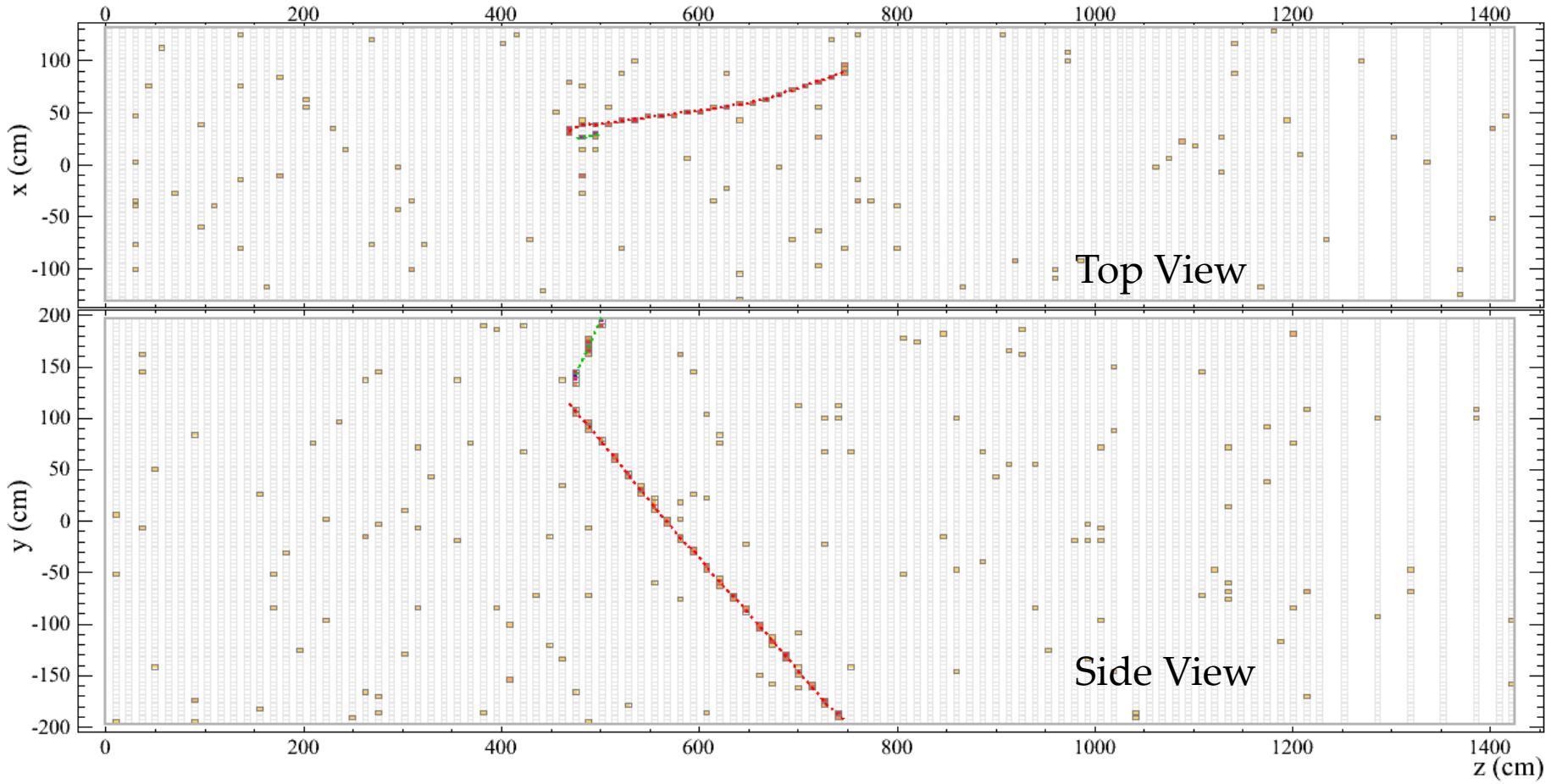
Event: 314724

UTC Tue Dec 21, 2010  
11:48:18.997623872



20 September 2012

# Reconstructed Simulated $\nu_\mu$ Event



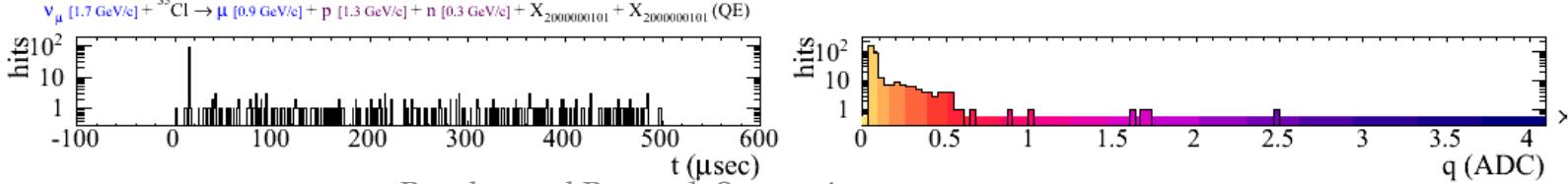
NOvA - FNAL E929

Run: 1 / 0

Event: 1685 / NuMI

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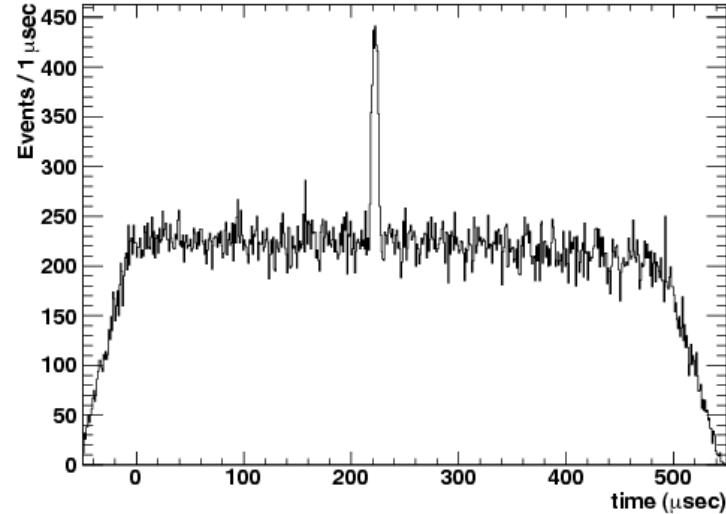
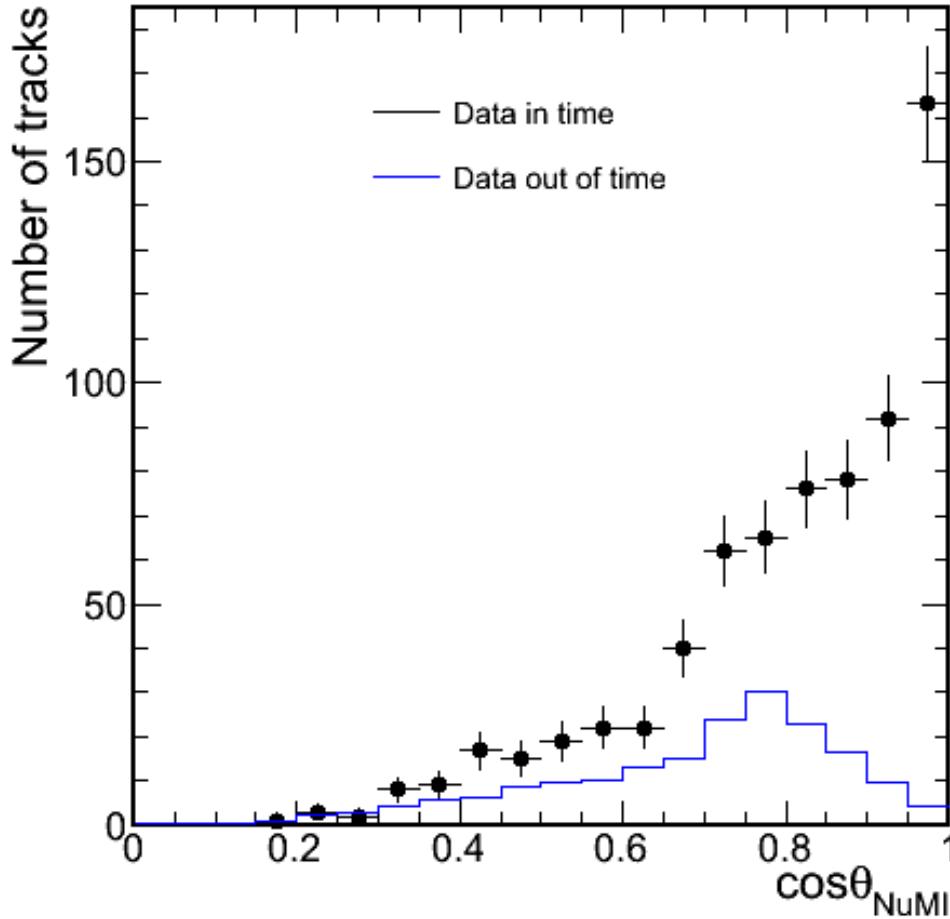


20 September 2012

Postdoctoral Research Symposium --  
Timothy Kutnink

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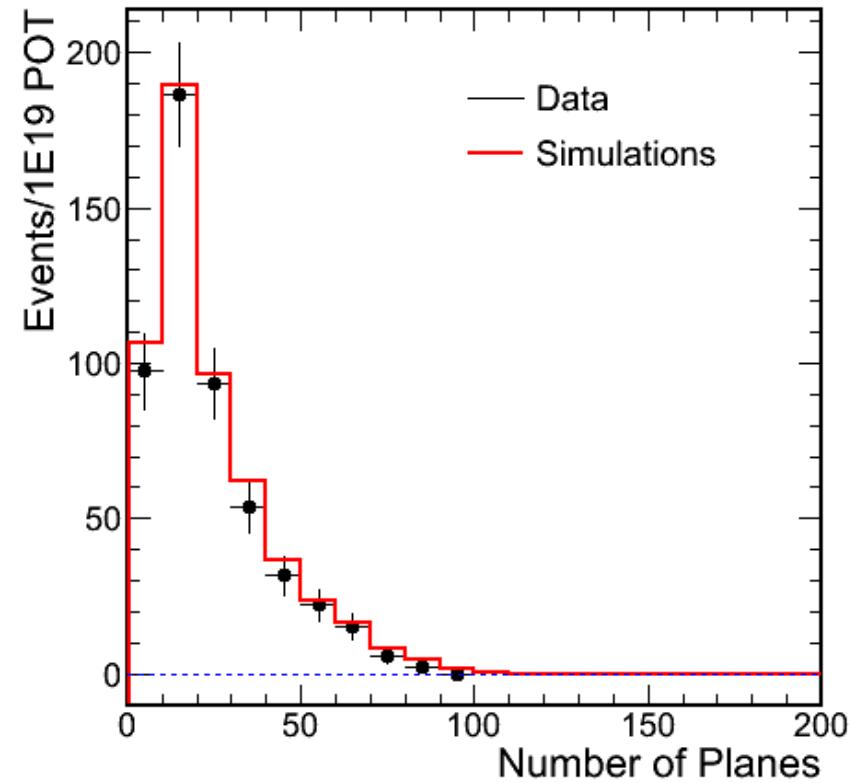
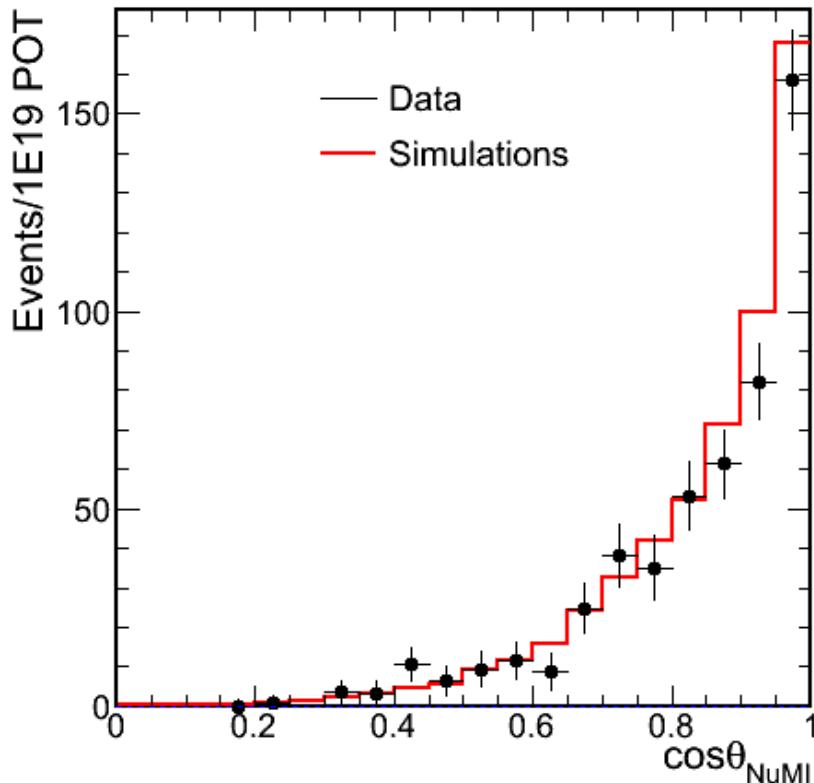
# Neutrino Data from the NuMI Beam



- Data trigger for the NuMI beam is  $500 \mu\text{sec}$  window.
  - The neutrino spill time is  $10 \mu\text{sec}$ .
  - The peak is seen at  $222 \mu\text{sec}$ .
- A time window of  $10 \mu\text{sec}$  is applied to define the data in time.
- The angle between the track and the NuMI beam shows a clear peak for the data in time.
- The data corresponds to  $9.6 \times 10^{18}$  protons on target (POT).

# Neutrino Candidates from the NuMI Beam

- After subtracting the background from the in-time data, we obtain neutrino candidate distribution.
- Comparisons to simulated neutrinos matched well in direction and length.



# Conclusions

- The NDOS finished collecting beam neutrino data on 1 May 2012.
- We are continuing to test the stability of operations with cosmic ray muon data.
- We are making progress towards developing calibration and reconstruction methods, as well as physics analyses.
- NOvA will start taking data in April 2013 with 1/3 of the detector constructed.
- We look forward to exciting results!



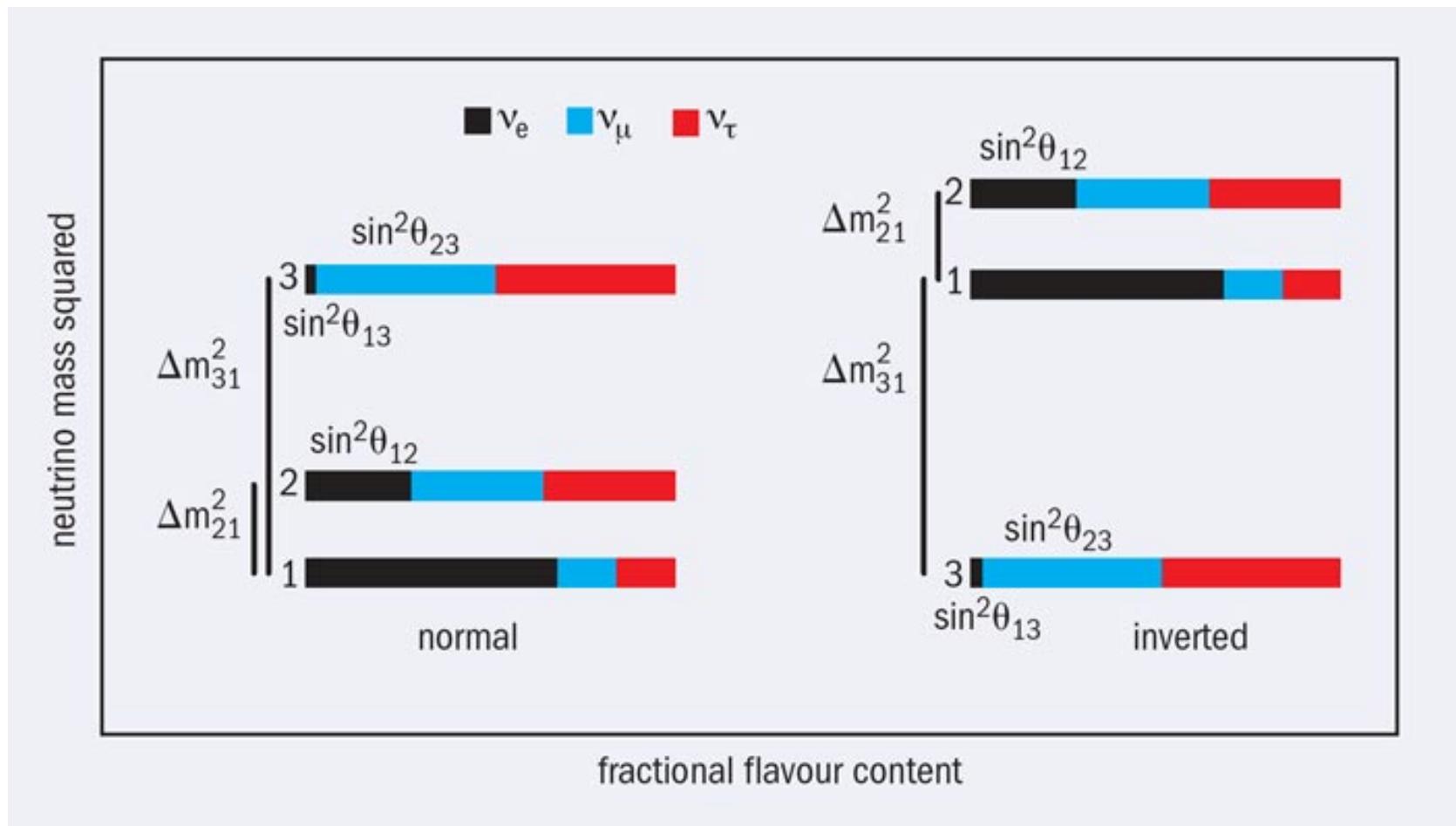
# Back-Up

# PMNS Mixing Matrix

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

- (12) Sector: Reactor + Solar, L/E~15,000 km/GeV  
 $\Delta m_{21}^2 = 7.50_{-0.20}^{+0.19} \times 10^{-5} \text{ eV}^2$      $\tan^2 \theta_{12} = 0.452_{-0.033}^{+0.035}$
- (23) Sector: atmospheric and accelerator, L/E~500 km/GeV  
 $|\Delta m_{32}^2| = 2.32_{-0.08}^{+0.12} \times 10^{-3} \text{ eV}^2$      $\sin^2(2\theta_{23}) > 0.96$  (90% C.L.)
- (13) Sector: Reactor and accelerator, L/E~500km/GeV  
 $\sin^2(2\theta_{13}) = 0.096 \pm 0.013$

# Mass Hierarchy and Three Neutrino Mixing

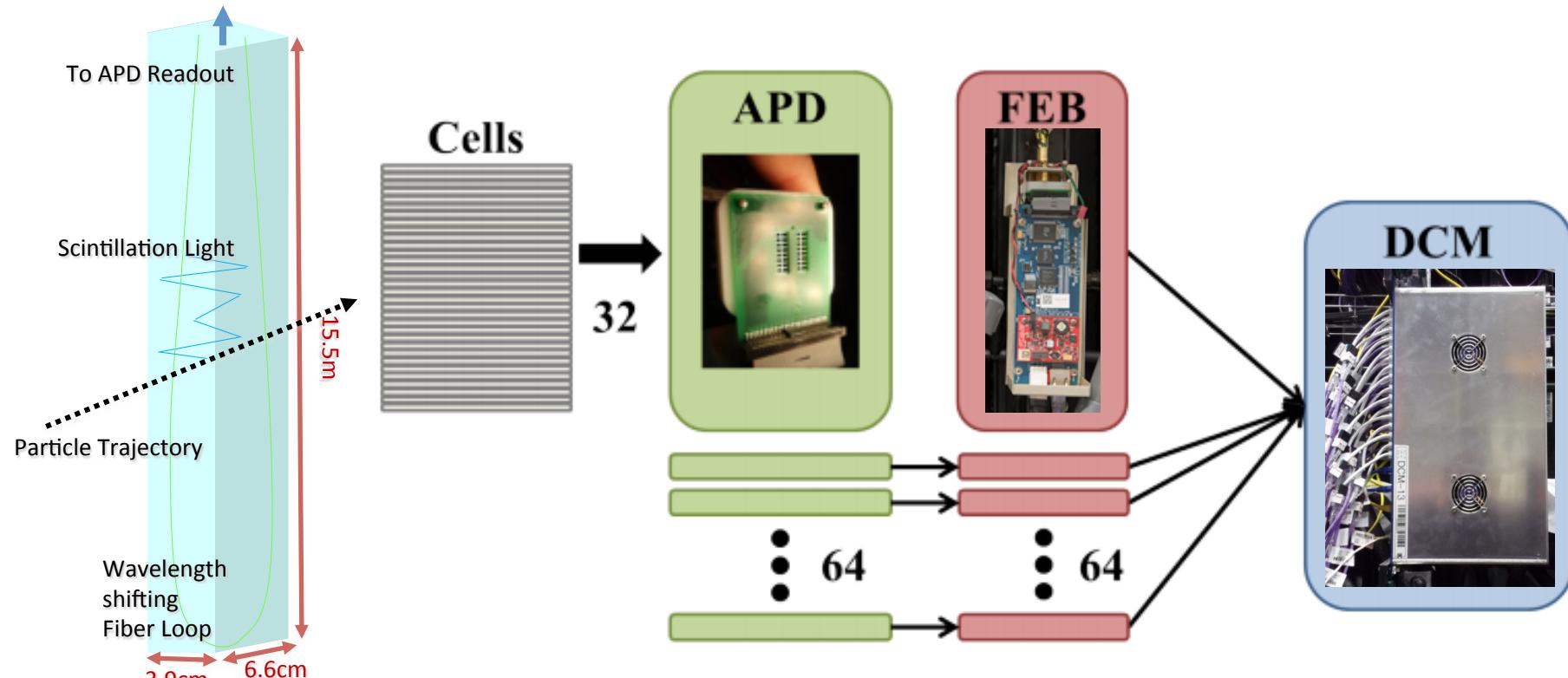


# Three Neutrino Mixing



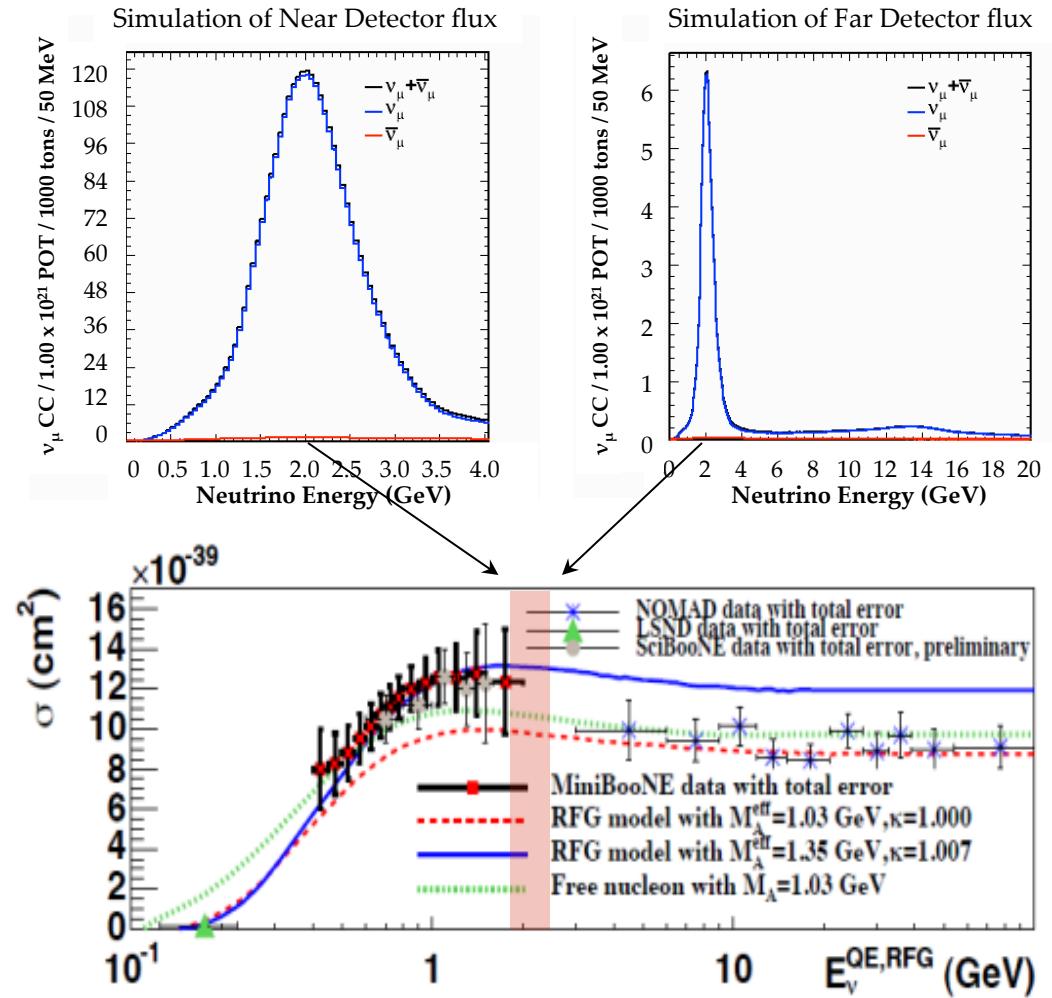
# The Detector Technology

- Light is generated by charged particles and collected by wavelength-shifting fiber.
- Each avalanche photodiode (APD) reads out 32 cells.
- Each APD is connected to a Front End Board (FEB).
- The FEB digitizes signal, sends it to a Data Concentrator Module (DCM).
- Each DCM can read 64 FEBs. The NDOS uses 11 DCMs.

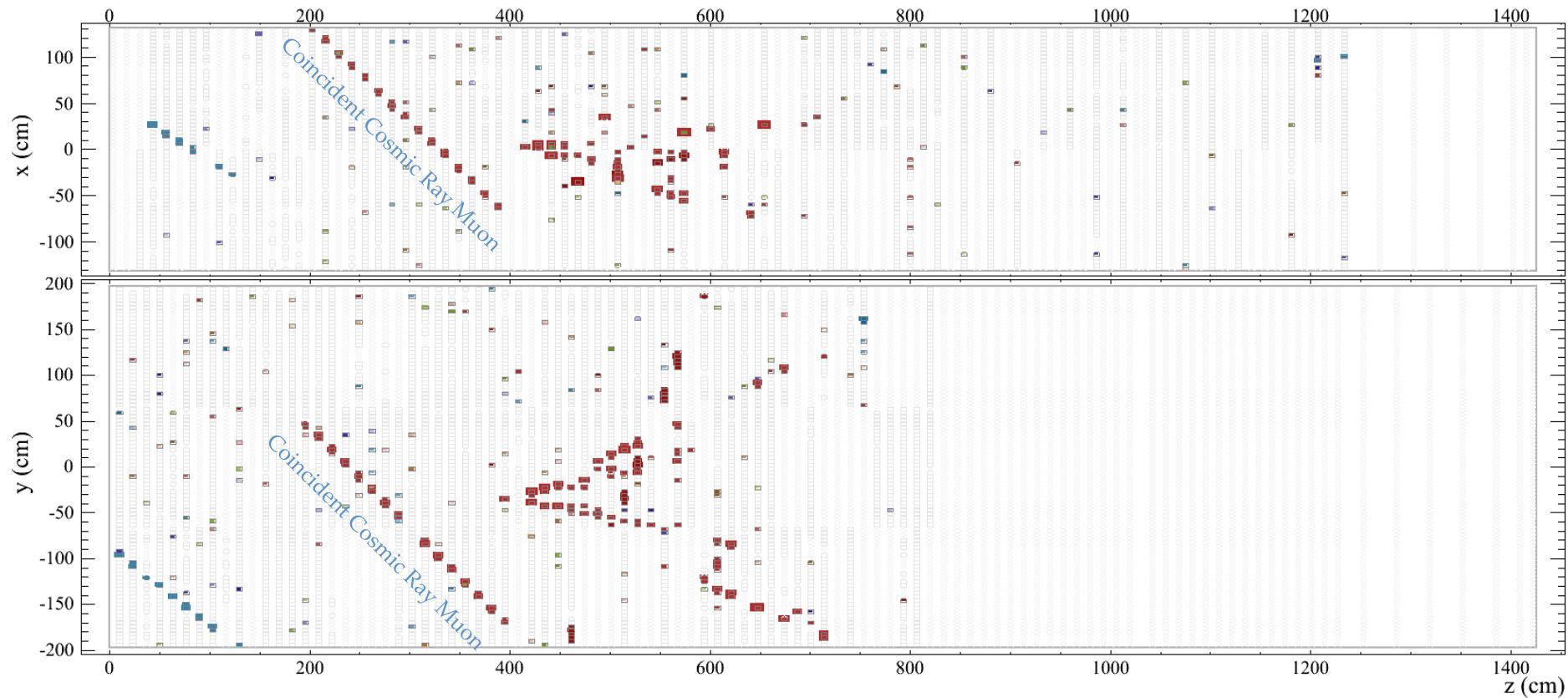


# NO<sub>v</sub>A Quasi-Elastic Studies

- The neutrino energy spectrum at the NO<sub>v</sub>A Near and Far Detectors is peaked at 2 GeV.
- The quasi-elastic cross-section at 2 GeV is not well known.
  - Measurements from other experiments disagree in this region.
- We will use the NO<sub>v</sub>A Near Detector to measure this cross-section.
  - We are using NDOS data to develop this analysis.

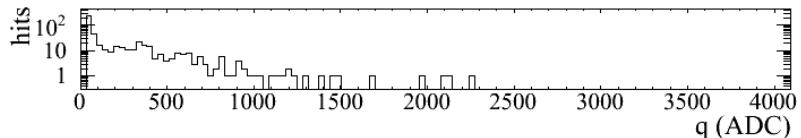
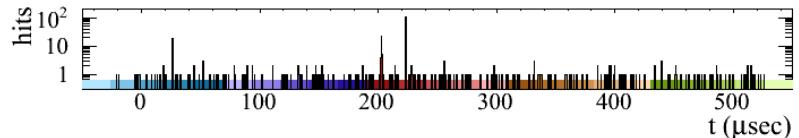


# Neutrino Candidate - Data

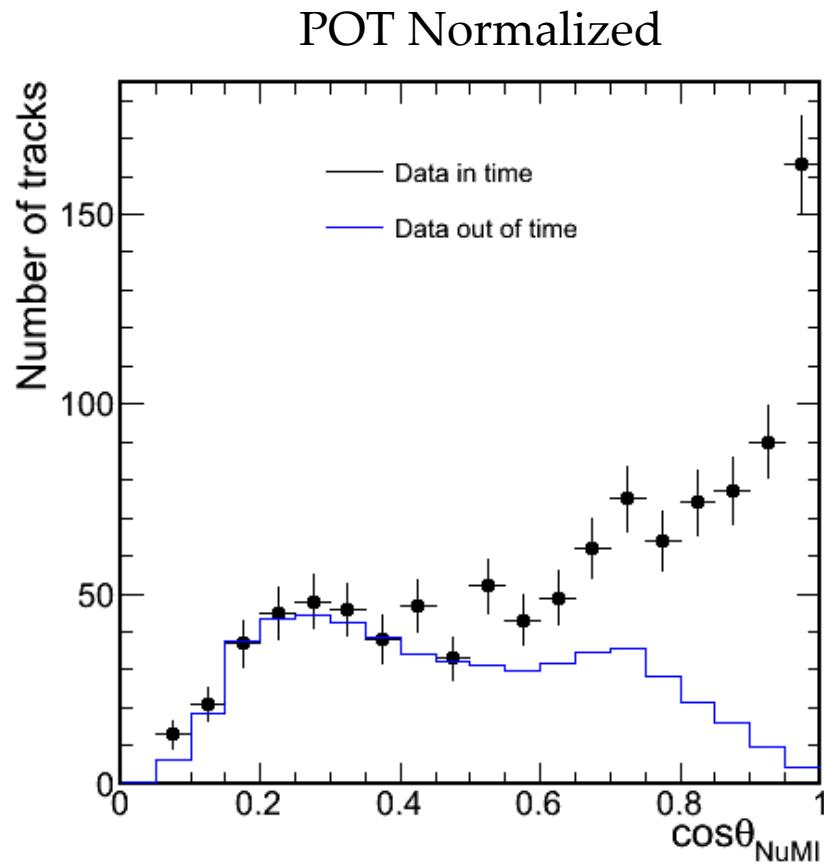


**NOvA - FNAL E929**

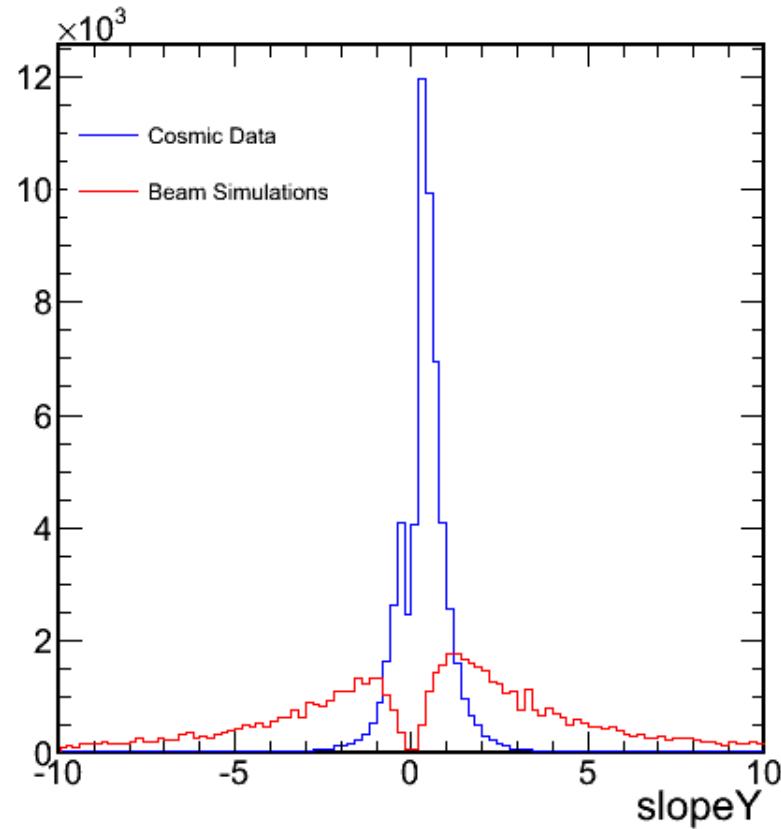
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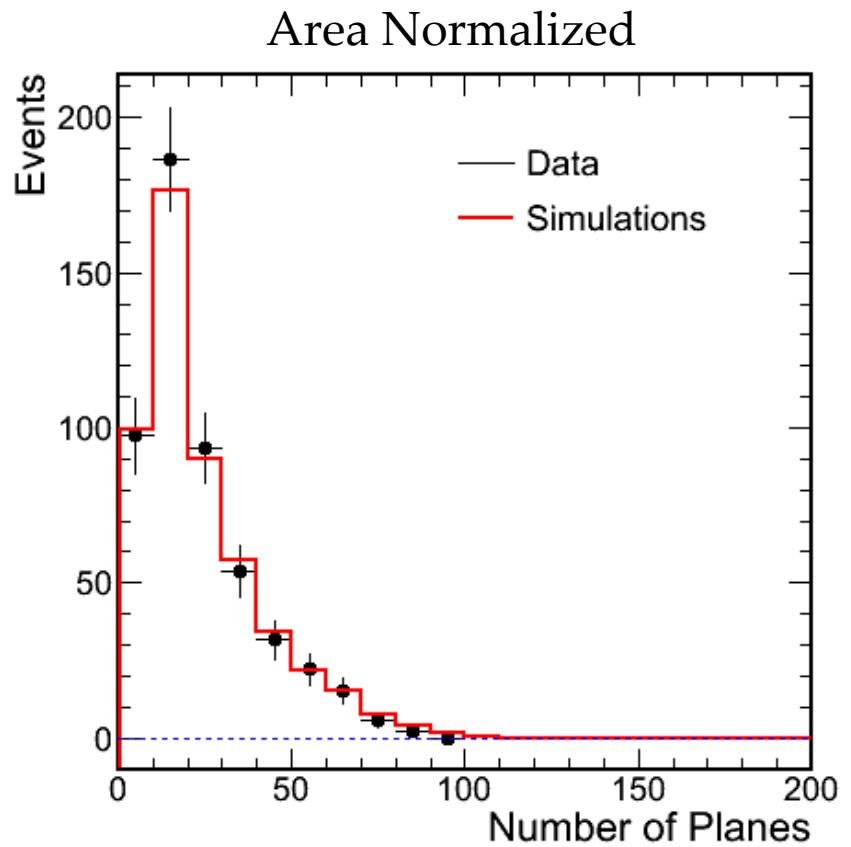
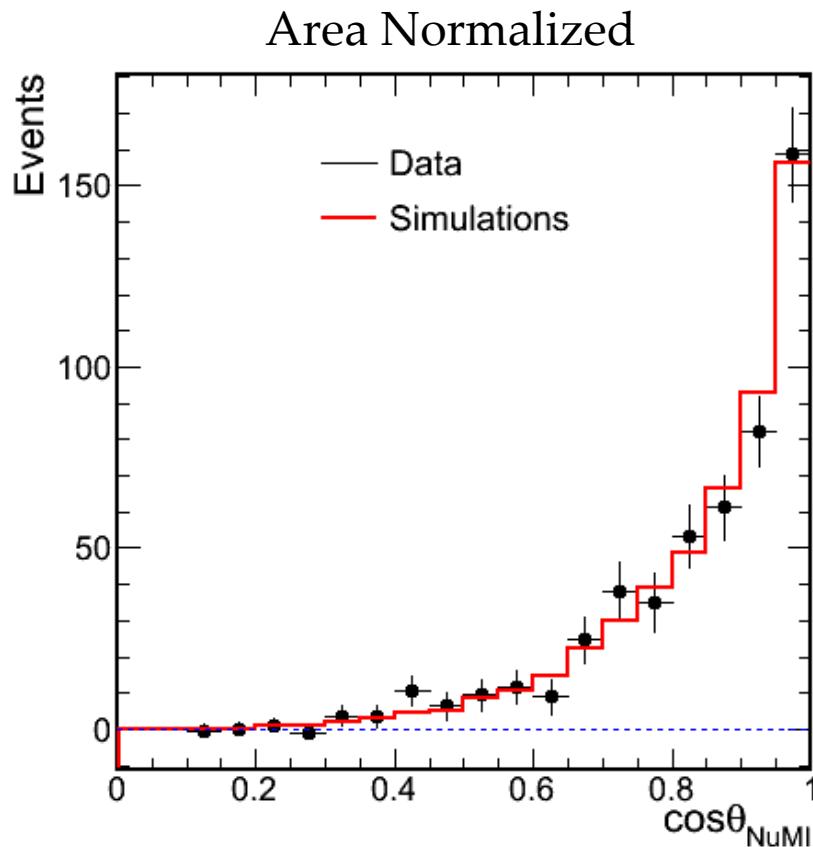
# Neutrino Candidates from the NuMI Beam



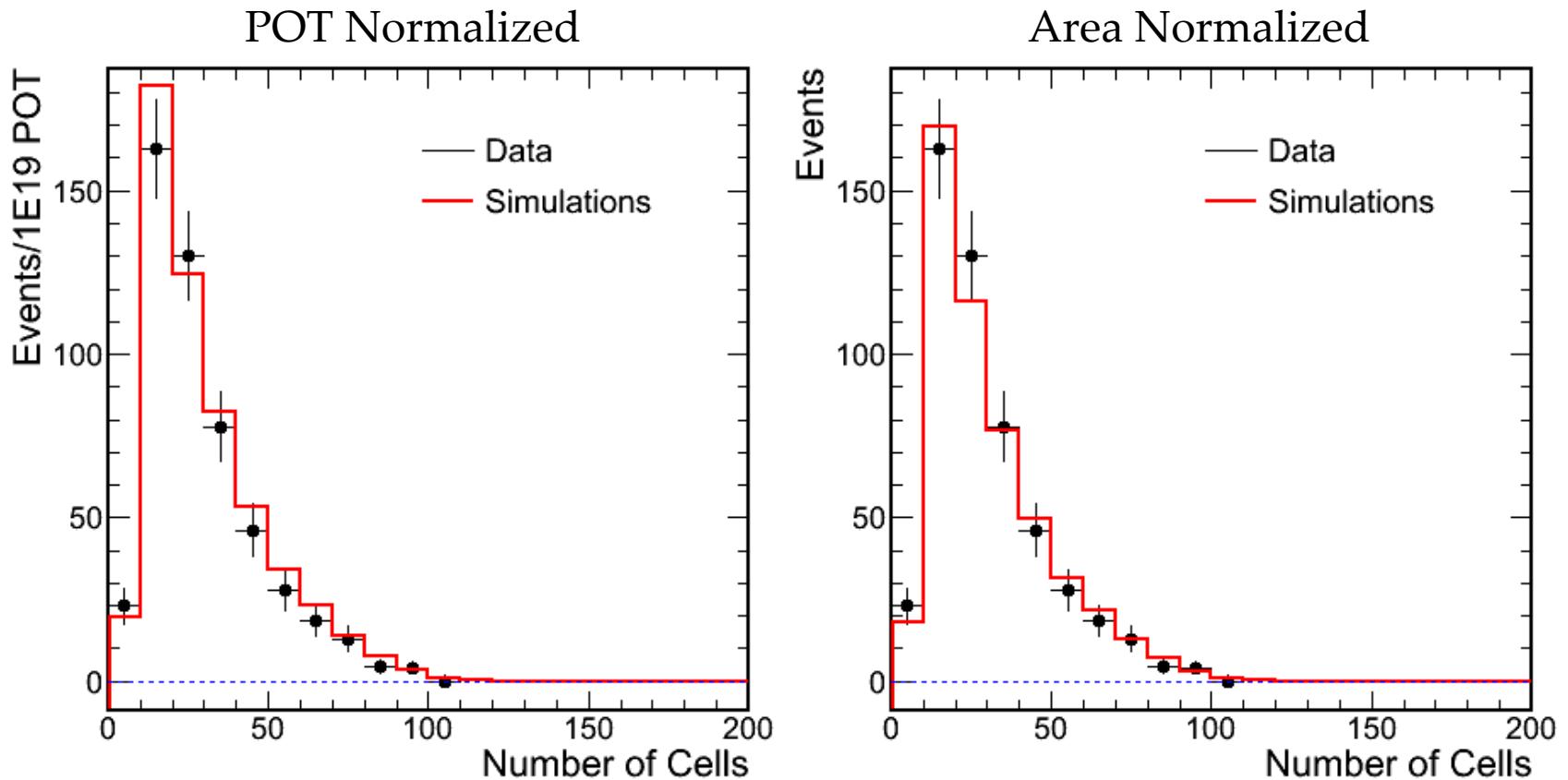
# Neutrino Candidates from the NuMI Beam - Criterion



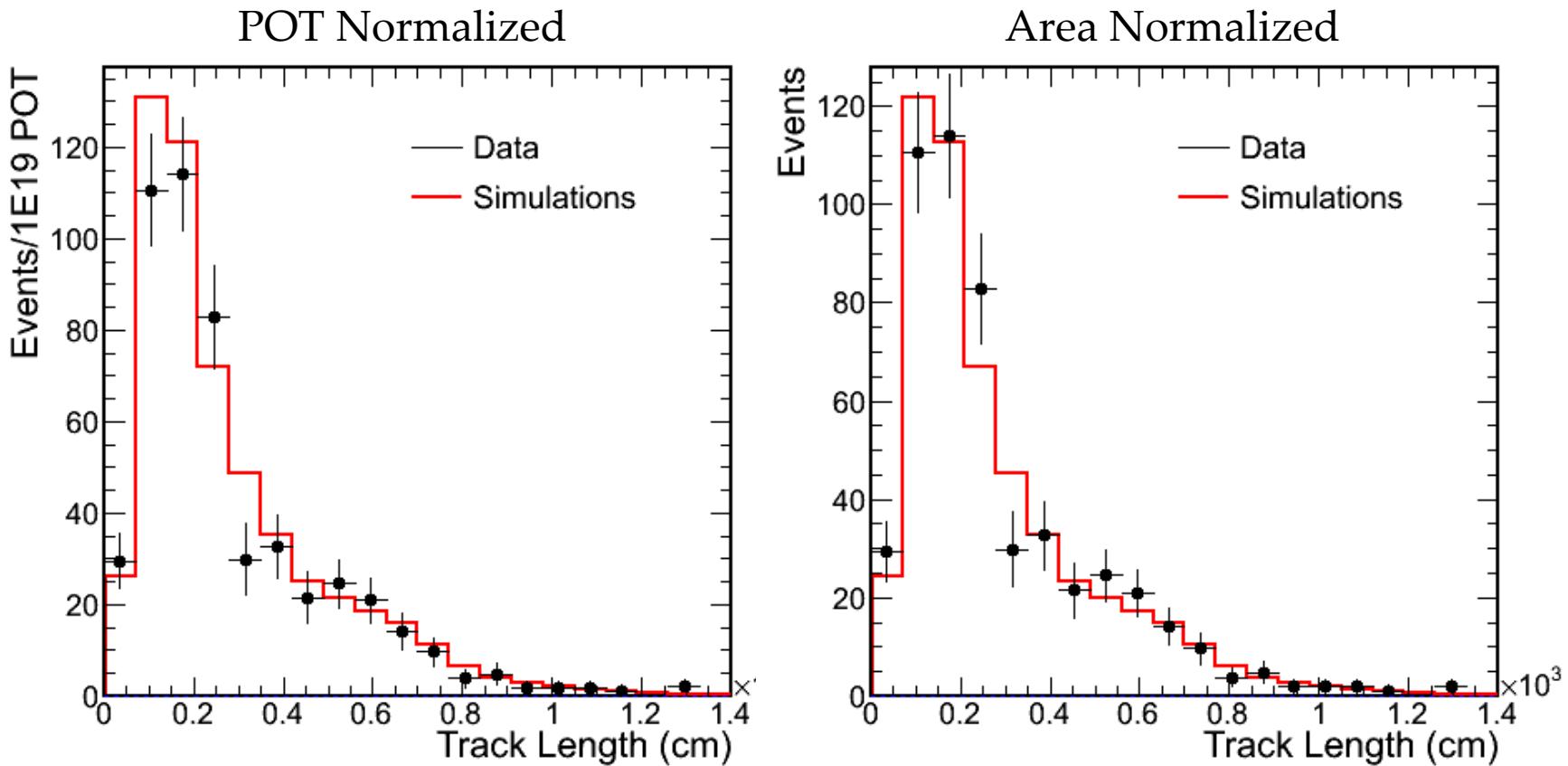
# Neutrino Candidates from the NuMI Beam



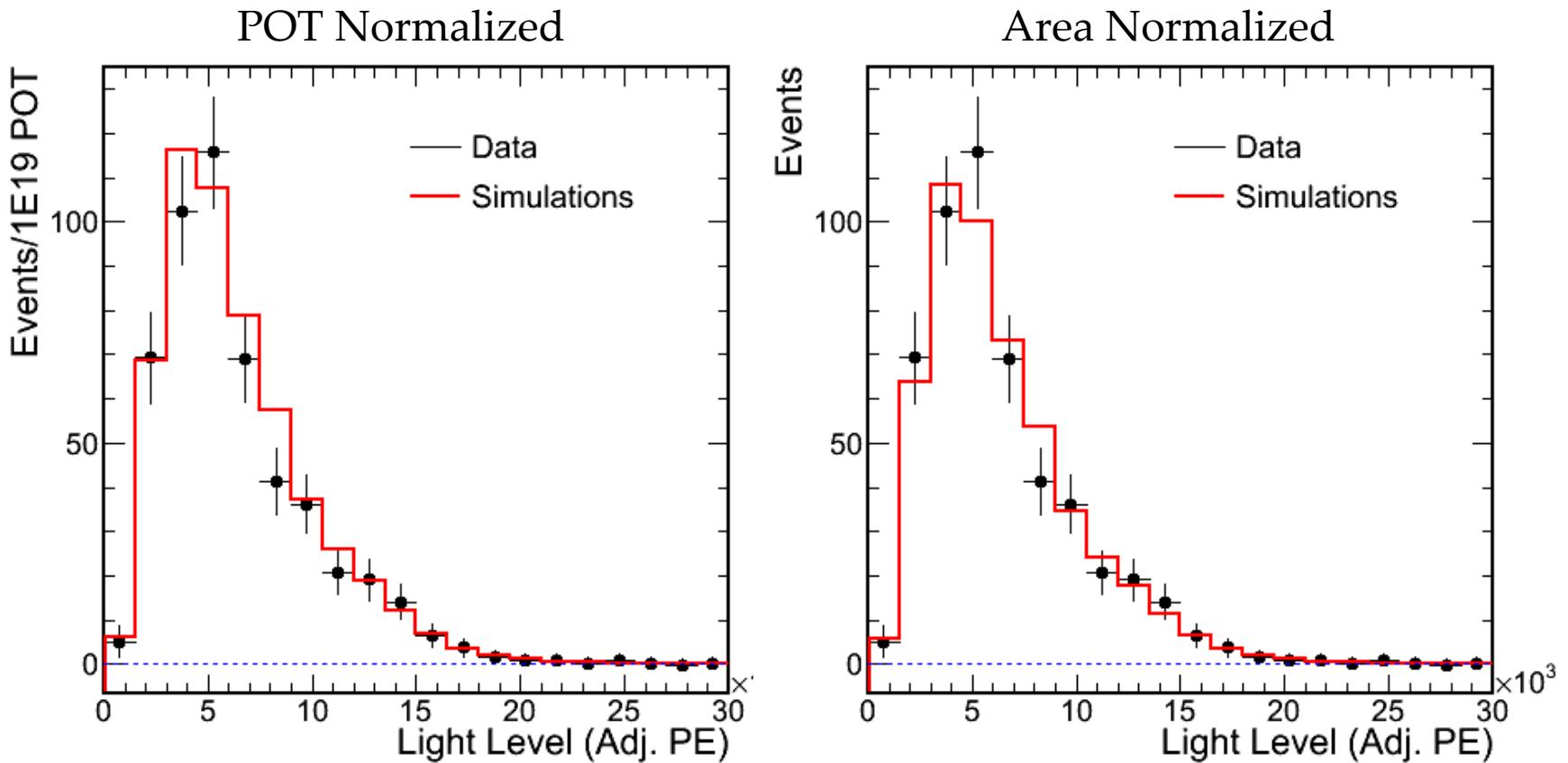
# Neutrino Candidates from the NuMI Beam



# Neutrino Candidates from the NuMI Beam



# Neutrino Candidates from the NuMI Beam



# Neutrino Data from the Booster Beam

